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Fig. 1.

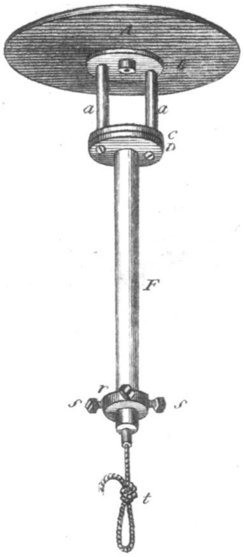


Fig. 2.
Half Size.

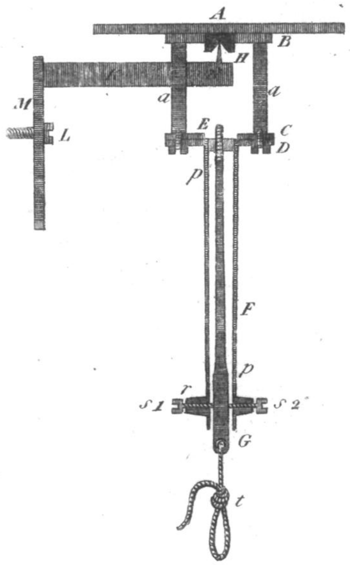


Fig. 3.

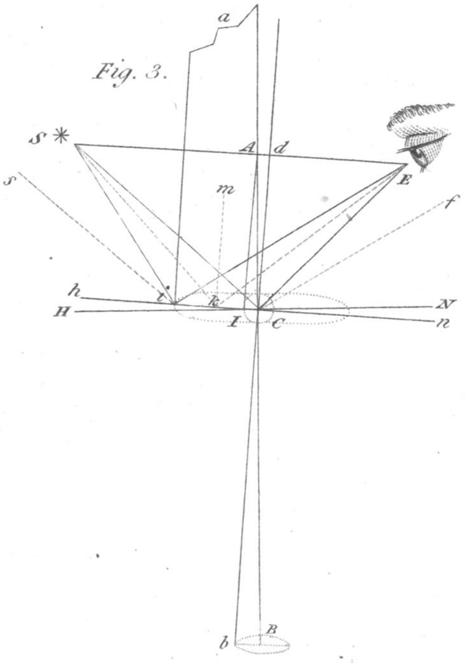


Fig. 4.

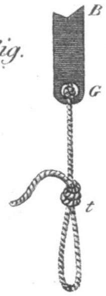


Fig. 7.

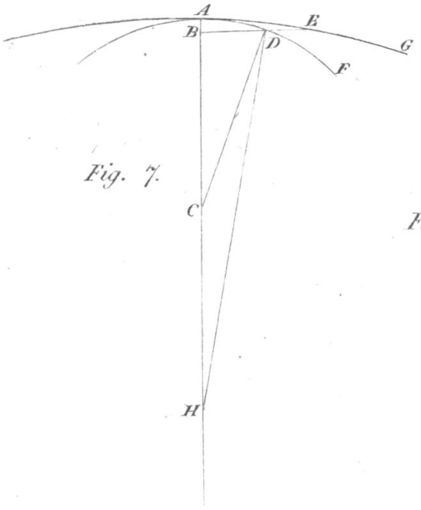


Fig. 6.

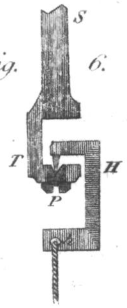


Fig. 5.

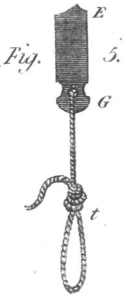
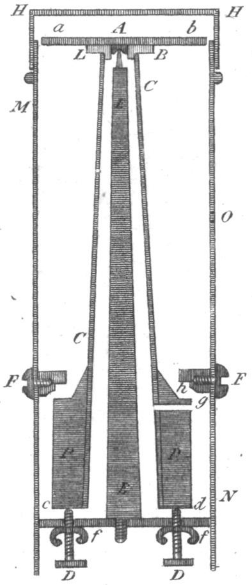


Fig. 8. ⅓ Size



J. L. del.

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A DESCRIPTION *of a* REFLECTING LEVEL *or an* ARTIFICIAL HORIZON *for taking* ALTITUDES *of the* CELESTIAL BODIES, *&c. on Land by* HADLEY's QUADRANT, *with ſome* REMARKS *on different* LEVELS. *By the Reverend* JAMES LITTLE.

Read October 20th, 1798.

THE uſefulneſs at ſea of that excellent inſtrument, the Hadley's quadrant, is known to every navigator, it being the only one by which, without any ſtand or fixed poſition, and even when the obſerver is in motion, accurate obſervations can be made of the altitudes of the celeſtial bodies and their angular diſtances in order to find the longitude; and it would alſo, as being the moſt accurate and ready of all ſmall and portable inſtruments of that nature, be exceedingly uſeful at land, eſpecially to a traveller, in taking curſory obſervations, to diſcover the latitude, &c. of places occaſionally viſited, if it were furniſhed with an artificial horizon or level to ſupply the place of that natural one which at ſea the water around the obſerver affords, and from which the altitudes of the celeſtial bodies are meaſured: for want of ſuch a level on land, they who make obſervations with an Hadley's quadrant, which is not fixed and adjuſted by a plummet or ſpirit-level, are obliged to take theſe altitudes by meaſuring the angular diſtance between the object and the image of the ſame ſeen on the ſmooth and level ſurface of a ſtagnant fluid, as water, quickſilver, &c.; and when the object is very remote, that angular diſtance will be double its elevation above the real horizon. But as ſuch obſervations muſt be made in the open air, and the leaſt breath of wind will ruffle the ſurface of the fluid, it is neceſſary to cover it with two glaſs planes joined at their upper edges and erected like the roof of a houſe over the veſſel containing the fluid: each of theſe planes muſt have its oppoſite ſurfaces exactly parallel, which is never the caſe with plates of looking-glaſs, and the proper planes with the requiſite apparatus are in few places to be procured, and liable to accidental injury. Inſtead of this fluid artificial horizon I have uſed the following one, which can any where be eaſily made, and which I found to anſwer well, as being accurate and portable, leſs liable to accidents in travelling than the former, and diſcovering in the act of obſervation its own errors of adjuſtment. I conſtructed it in the two forms hereafter deſcribed, the firſt of which is repreſented in a perſpective view in fig. 1, and in a ſection through the middle in fig. 2: the ſecond form appears in fig. 8, in a like ſection through the common axis of its parts.

IT conſiſts of a circular plate of glaſs *A*, (made of a piece of looking-glaſs) whoſe upper ſurface is plane and poliſhed, but the under ſurface has its poliſh taken away by being rubbed with a piece of lead and flour of emery with water, ſo that an image of any object can appear by reflection from its upper ſurface only: to this is cemented with black ſealing-wax the frame *B C*, (made of ſteel, or it might be of braſs) both having been previouſly made very clean and bright and heated in an oven, then cooled ſlowly: this frame is compoſed of the round plates *B* and *C* faſtened together by the two rods or pillars *a a* ſtrongly riveted or brazed to both plates: the piece *D E F* is compoſed of the round plate *D*, which is exactly fitted and ſcrewed cloſe and immoveable by two ſcrews to the plate *C*, ſo that both may be parallel to *A* and *B*. In the middle of the plate *D* is brazed the pipe *p p*: this pipe is made of ſteel, and its ſides as thin and light as may be conſiſtent with ſtrength to ſecure it from being eaſily bent; it tapers a little towards its end, and its mean external diameter is about $\frac{1}{10}$ of an inch: in the middle of this pipe is a ſteel wire hardened towards the lower end and tapering upwards towards *E*, where it is ſcrewed (looſely) through the middle of a ſhort pin or plate faſtened in the mouth of the pipe, which pipe is (for ſtrength) inſerted quite through the plate *D*. The lower end of the wire, which extends a little below the pipe, has a hole through it at G at right angles to its axis, as repreſented (enlarged) in fig. 4, and alſo in fig. 5 in another ſection of the wire which is at right angles to the ſection in fig. 4: this hole is to contain the knot of a looped thread *t*, which is inſerted through a very ſmall perforation made in the axis of the wire, and only ſo wide as juſt to admit the thread tight through it, or inſtead thereof a very fine and flexible ſtring of cat-gut or fiddle-ſtring, in order that when a weight is appended to the ſtring it may pull the wire only by a point in its axis. A ring or hoop *r r* (of iron) is brazed on the lower end of the pipe *p p*, juſt ſo broad as to admit four equidiſtant and oppoſite adjuſting ſcrews *s s*, (made of tempered ſteel, and having ſquare heads, in order to be turned by a key as well as by a turn-ſcrew) to be inſerted through it; and the hoop is to be ſo thick as to ſuſtain, without change of its circular ſhape, the preſſure of the ſcrews againſt the wire *G E*. The pipe *p p* is to be fixed perpendicular in the plate *D*, that it and alſo the wire *E G*, when in the middle of it, may be at right angles to the mirror; and then any little deviation of the wire from this will be corrected by moving the wire (which muſt be ſo fixed as to yield eaſily) towards that ſide where it makes too great an angle with the mirror, which is done by firſt withdrawing the adjuſting ſcrew on the ſame ſide and then advancing the oppoſite ſcrew: and when the wire is thus firmly preſſed by the four oppoſite ſcrews it cannot change its poſition after being made vertical to the mirror, nor conſequently the inſtrument alter its adjuſtment.*

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* The plate *D* might be omitted, and the pipe with the wire *E G* might be faſtened in the plate *C*, were it not that there ſhould be a hole left in the middle of this plate to allow the needle-cap (hereafter mentioned) to be fixed in the plate *B*, and

In making this little inſtrument care muſt be taken to form it ſo, that when the frame *B C*, and its appendage *D F*, are ſcrewed together, then the common axis *A G* of the whole ſhall paſs through the centre of the plate *A* and be at right angles to its plane; for when this is the caſe, if it be contrived to ſuſtain the axis

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and if made of ſteel, to be poliſhed anew, ſhould it ever contract ruſt; to prevent which it would be beſt to keep always a drop of oil in it. The wire ſhould be ſo thick at the place of the ſcrews that its diameter may be only about $\frac{1}{12}$ of an inch leſs than the internal diameter of the pipe, and when the inſtrument is adjuſted the wire ſhould be as nearly as poſſible in the middle of the pipe; for if it were removed too much to one ſide, each pair of the ſcrews, whoſe ends are all equidiſtant from one another, would not preſs the wire in points of it diametrically oppoſite; in which caſe the withdrawing of one ſcrew alone might not permit the motion of the wire to that ſide, but it might be requiſite to eaſe two contiguous ones, and create a neceſſity for altering all the ſcrews, which would render the adjuſtment very troubleſome. This will be avoided by making the wire as thick as it may conveniently be juſt at the place of the ſcrews, and by having the pipe fixed at right angles to the mirror.

Another method of appending the weight to the ſtem is repreſented enlarged in fig. 6. The lower part of the ſtem is formed as at *S T*, and a pin P made of hardened ſteel is ſcrewed into it, in whoſe end is a conical cavity with a fine apex to receive the fine and hard point of a hook *H*, made of a thin plate of ſteel and faſhioned as in the figure: through a hole in the hook at *h* a ſtring is put to ſuſtain the weight, which it is plain will thus pull the ſtem only by that point in its axis which is the vertex of the conical cavity. Whether this or the above method of ſuſpending the weight is the beſt, I can't ſay, though I have tried both; but would rather recommend the former as being more ſimple, and conſequently fitter for a portable inſtrument, which ſhould conſiſt of as few parts and common materials as poſſible, leſt any ſhould be loſt, deranged, or damaged. I made trial of a ſmall ring (to hang the weight from) paſſed through the end of the ſtem which was made thin, but it would not anſwer.

axis *AG* in a vertical poſition, the plate *A* will be kept in an horizontal one, and will be a reflecting level: this is effected by ſuſpending the whole from a point *N*, (fig. 2.) in the axis, as near the plate *A* as can be, and hanging from the looped ſtring *t*, by a hook, a weight to ſwing in a veſſel of water, or in the air if it be calm enough. The point of ſuſpenſion is in the axis of a pin of ſteel *H** (tempered very hard) inſerted through and fixed in the plate *B*, having a conical cavity in it, whoſe apex is poliſhed to receive the point of a ſtrong and hard tempered ſteel needle *N*, which needle ſupports the inſtrument, and is itſelf ſuſtained perpendicularly in an iron arm *K*, riveted in the plate *M*, by which it is faſtened by the ſcrew *L* on the inſide of a veſſel or caſe about eight inches deep and near three inches wide internally: the arm *K* has ſuch a length and poſition as that the needle *N* ſhall be in the middle of the veſſel: this veſſel is to reſt or be ſuſtained ſteady on ſome ſtand, or to be ſteadily faſtened by a ſcrew in an upright ſituation to a firm door-poſt, tree or wall, &c. when the veſſel is vertical its upper edges muſt be level, and the arm *K* muſt be placed ſo high as that the upper ſurface of the plate or mirror ſhall be very little higher than the edges of the veſſel: the lower part of the veſſel is to hold water ſufficient to cover the weight, and the upper part is to have a door in the ſide to allow the inſtrument to be ſuſpended and its weight hung by a hook from the loop of the thread *t*, or its vibrations to be ſtopt; for which purpoſes the door ſhould deſcend to near the ſurface of the water: it is to be ſhut at other times to prevent the wind from agitating the level.

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* A ſtrong agate needle-cap, ſuch as is uſed for compaſs-needles and fixed in the plate *B*, would anſwer beſt.

From this deſcription it is evident, that when the inſtrument is ſuſpended from the point *N*, under the centre of the mirror, and the weight appended to *G*, or the middle point of the hole in the axis of the wire, theſe two points would be always in the line of the direction of gravity if the inſtrument itſelf had no weight, or if that line paſſed through the centre of gravity of the whole machine; but if the glaſs plate and metal frame could be divided into two parts, of unequal weight, by a plane paſſing in any direction through *A G*, then the axis *A G* would be thrown out of the direction of gravity, and conſequently the mirror out of the level more or leſs as the weight appended at *G* is leſs or more: this can ſcarce happen if the point of ſuſpenſion *N* be in the centre of the plates *A* and *B*, each of the plates *B*, *C* and *D* be of uniform thickneſs, the pillars *a*, *a*, of equal ſize, equidiſtant from *N*, diametrically oppoſite and at right angles to the plates *B* and *C*, and the ſtem *E F*, in the middle of the plate *D*, and perpendicular to it; and thus the line *A G* be the vertical axis of the whole and of each of the parts: this

eaſily

eaſily may, and muſt at firſt be nearly effected; which will be known in ſome meaſure by the plate *A* reſting level when the inſtrument is ſuſpended on the needle *N* without any weight hung from the end of the ſtem; and if it could be effected accurately there would be no uſe for the pipe *p p*, and a ſolid ſtem *E F* might be fixed in the plate *D*; but when the weight is hung from the ſtem and the inſtrument receives a circular motion round the plumb-line (which certainly may be conſidered the ſame as *A G*,) it will be found that the image of a fixed object ſeen by reflection in the mirror, by an eye kept alſo fixed or viewing it through a fixed ſight or vane, will not during the motion of the inſtrument appear every where at the ſame diſtance from the centre or edges of the circular plate or mirror, but the image will move or ſhift its place in it; a certain proof that this was not horizontal, and that though the line *A G* is inſenſibly different from the line of gravity, yet that it was ſcarce poſſible to fix that line at right angles to the plate, but that there was a neceſſity for adjuſtment: for this purpoſe therefore the four adjuſting ſcrews *s s* were added, whoſe mode of action and effect have been explained.

If during almoſt half a revolution of the mirror round the axis *N G*, (which motion the arm *K* being made purpoſely thin and the pillars *a a* ſmall will allow) the reflected image of a fixed object ſeen as above-mentioned appears alſo fixed, the mirror is as perfectly horizontal as the plumb-line is vertical; ſuppoſing the ſurface of the mirror to be a true plane, (and one muſt be unlucky indeed in the choice of a piece of looking-glaſs if it be not ſufficiently ſo); and as it can by the adjuſting ſcrews be regulated to as much preciſion as the eye, even aſſiſted by a teleſcope, can aſcertain the contact of two images, and alſo proves its own adjuſtment, (by turning it round on its axis), which can be farther verified by comparing angles taken by reflection from it with thoſe taken from the ſurface of a fluid; alſo as it does not ſeem likely to change its form after being adjuſted and the ſcrews made firm; it ſeems in this reſpect unexceptionable, and it may be adjuſted the way before-mentioned by obſerving the image of any fixed object, as the ſun or moon, the top of a mountain or building, a candle placed at the diſtance of ten or fifteen feet, a wafer faſtened on the glaſs-pane of a window, &c. if when the mirror is made to revolve round the axis *A G*, without any pendulous vibration of the weight, the image *firſt aſcends* towards the part of the mirror moſt remote from the eye, and *then deſcends*, that part of the mirror in which the image is ſeen moſt elevated or culminating alſo aſcends or is raiſed above the level; and it will be lowered by firſt unſcrewing a little the adjuſting ſcrew which is neareſt to the moſt elevated place of the image on the ſame ſide, and then ſcrewing up the oppoſite ſcrew; for this will make the end of the ſtem approach towards or make a leſs angle with the mirror on the ſide where that angle was too great, i. e. where the mirror was too much elevated: alſo if the image, during the revolution of the mirror, appears *firſt to deſcend* towards the obſerver, and *then to aſcend*, that part of the mirror in which the image is loweſt is too much elevated above the horizon, and it will be depreſſed by withdrawing the ſcrew next to the loweſt place of the image, (which is now the higheſt part of the mirror) and advancing the oppoſite ſcrew as before; ſo that the adjuſter muſt be cautious not to miſtake *the order* of the aſcent and deſcent of the image, nor the *direction* of its *motion*; for as it has (in every complete revolution) both an aſcent and deſcent towards and from the higheſt and loweſt points, if the obſerver miſtakes the one for the other he may move the ſcrews erroneouſly, ſo that he muſt previouſly aſcertain the higheſt and loweſt place of the image.

THAT it is by the elevation of the mirror on the ſide in which the image appears it is made to aſcend, may be ocularly demonſtrated by giving that diameter of the mirror, which is in the ſame plane of reflection with the eye, the object, and image, an angular motion in that plane upon the point of ſuſpenſion; but if one would chooſe to know the optical reaſon of this effect and of the preceding directions, (and the knowledge of the theory of any inſtrument enables the reader to appreciate its merits, and alſo precludes injudicious attempts at alteration or improvement; on which accounts I think the theory ſhould accompany the deſcription of every machine); he may underſtand it from conſidering the following circumſtances; and indeed ſince differences in the diſtances of the near objects, by which alone this mirror, when not level, could ſometimes be adjuſted *, will produce a variety of motions and places of the reflected image, while the mirror is turned round the plumb-line, even when the altitude of the objects does not vary, and *vice verſa*, differences in the altitudes when the diſtances are unvaried; which might puzzle and diſguſt the perſon adjuſting it, and create doubts of its accuracy, it is the more neceſſary to give ſome explanation of its optical properties when it is propoſed for uſe.

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* Though the want of adjuſtment of this level may be diſcovered in every obſervation of the celeſtial bodies, in which caſe their great diſtance renders the place of the eye, and conſequently of the quadrant uſed, immaterial; yet it can ſcarcely be adjuſted by an obſervation of the ſun, &c. unleſs they are very near the meridian; when there might not be time enough to accompliſh it, and alſo unleſs the altitude of the ſun, &c. be not too great: therefore the ſun will not anſwer well for adjuſting it in low latitudes, nor the moon except when at full: it will on theſe accounts be moſt generally convenient to adjuſt it by a near object, in which caſe the eye muſt be fixed, and then there will be a greater variety in the motions of the reflected image on the mirror, according to the relative diſtances of the eye and object from it; and there ſhould be an attention to more circumſtances in the proceſs of adjuſtment: wherefore I thought it proper to give ſome account of theſe particulars.

In fig. 3, let the line *C B* repreſent the ſtem of the level, kept by the plummet in a vertical ſituation: if the inſtrument were truly adjuſted, *C B* would be the axis of the mirror and at right angles to its reflecting ſurface; but if it be inclined to this ſurface, then no diameter drawn on it will be at right angles to *C B* but one; all others will be inclined to it in various angles of obliquity, the greateſt being that at right angles to the diameter which has no inclination; and if the mirror revolve round the line *C B*, this latter diameter will deſcribe a circle, but the others intermediate between theſe two will deſcribe oppoſite conical ſurfaces, having all of them different angles at their common vertex *C*. Let *H N* be that diameter at right angles to *C B* the plumb-line, and conſequently in the horizon, and let it be in that plane in which the eye, fixed at the place *E*, ſees the image of a luminous point *S* in the point *C*: from the law of reflection, the angle *S C H*, made by the incident ray *S C* with the mirror, muſt be equal to *E C N*, made by the reflected ray *C E* with the ſame; let now the mirror revolve about the axis *C B*, 'till another diameter, ſuppoſe that which is moſt inclined to *C B*, viz. *h n*, falls into the plane of viſion or reflection *S H C E*; the image of *S* cannot now be ſeen at *C*, becauſe the ang. *S C h* is not equal to the angle *E C n*, and it can be ſeen only in a part of the mirror where theſe angles at the point of incidence will be equal, and that will be (when the object is very remote) at a point *i*, whoſe angular diſtane *C E i* from the point C is equal to twice HCb the obliquity of the ſpeculum[*], or becauſe the angle made by two lines or planes is equal to that made

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[*] When the object S is ſo diſtant that the ang. CSi is evaneſcent, the ray Si will fall on the mirror in the ſame direction as SC, that is, in Si parallel to SC: when the ray fell at C on the diameter HN, the angle of incidence was SCA, but in the change of the reflecting plane HC to bC, that ang. receives an increment HCb equal to BCb, and the ang. of reflection muſt receive the ſame; ſo that the angular velocity of the reflected ray is double that of the ſpeculum; and hence if the ang. ECf be made equal to twice BCb, Cf will be the reflected ray, and if the eye were at f, it would ſee the image at C, but the eye remaining at E will ſee it at i, in a direction parallel to fC, and at an angular diſtance CEi equal to ECf, from the point C; becauſe there the angles of incidence and reflection sia, Eia are equal, being the ſame as SCd, fCd. But if the object S be ſo near that the angle CSi or siS is of a ſenſible magnitude, then the incidence Sia is leſs than it was before, by the quantity of this angle, and the angle of reflection Eia muſt be equally diminiſhed, or both receive equal and contrary alteration, which will be when the image is formed at that point k, between i and C, where the angles of incidence and reflection Skm, Ekm will receive, the former ſuch an increment kSi, and the latter ſuch a decrement kEi, as will reſtore their equality. Hence it appears that if the diſtance of the eye remains unvaried, and alſo the elevation of the object HCS at the point C, the nearer the object S approaches this point, the nearer will the image approach to it; becauſe as the object accedes, the ang. CSi enlarges, and conſequently CEi muſt diminiſh.

But the various motions and poſitions of the image cauſed by the obliquity of the mirror to the horizon, cannot be clearly underſtood but by inveſtigating its path or place during a revolution of the mirror round the plumb-line. Let the line of direct viſion ES be drawn, bC be produced to d, and from the interſection A of SE and BC produced, let AI be drawn parallel to it, and from i let ia be drawn alſo parallel 'till it meets the axis BC produced, in the point a; ſince bC is perpendicular to the mirror, ſo alſo will be IA, ia (El. 11. 7.); and if the mirror be ſuppoſed to revolve round the made by two perpendiculars to the ſame, if *C b* be perpendicular to *b C*, it will be equal to twice *B C b*; ſo that when this angle is nothing,

the line *B A*, carrying with it with its own angular motion the lines *b d*, *I A* and *i a*, theſe will continue parallel and perpendicular as revolving together in the ſame plane with the line *b C*, which has no motion with reſpect to the mirror; but the line *A I*, as interſecting the line of ſight *E S*, and perpendicular to the mirror, is always in the plane of reflection, therefore ſo alſo will the other lines parallel to it, and the image will always be ſeen in ſome part of the lines *A I*, *a i*; but theſe lines have a conical motion round the common axis *B C a*, and therefore the image will partake of that motion laterally as well as directly, during the revolution of the mirror from the plane (repreſented in the fig. by the plane of the paper) in which the diameter *h C* is that moſt inclined to the axis of motion *A B*; and the extent of the lateral motion will be limited within the angle *C A I* by the line *A I* and not by any other line *a i*, becauſe the former terminates both in the axis of motion and alſo in the line of direct viſion *E S*, and has the ſame angular motion about this line, which the plane of reflection has during the revolution of the mirror; ſo that when the mirror or the diameter *h n* has made ¼ of a revolution from its ſituation in the fixed plane *E S H C*, the image will have deſcended from the place *i* to the the diameter *h n*, paſſing through the axis *A B*, and now at right angles to its former poſition; and will alſo have receded laterally from that axis to the diſtance *C I*, for it will always be ſeen in the diameter *h n* (which is moſt inclined to the axis and wherein the line *A I* reſts) during its revolution; and its diſtance, as meaſured on the ſurface of the mirror, from the plane *E C H S*, will be the ſine of the angle made by the radius *C I* in its revolution; and its diſtance, the ſame way meaſured, from a plane paſſing through *C* and at right angles to the former, will be the coſine of the ſame angle and deſcribed by the radius *C i*: and from this it appears that the path which the image traverſes on the ſurface of the mirror by the compoſition of ſuch direct and lateral motions during a revolution is an ellipſe, whoſe vertex is at *i*, its centre a point in the axis *C A*, its greateſt ſemiaxis the perpendicular diſtance between *i* and *A C*, and its conjugate ſemiaxis the perpendicular diſtance between *I* and *A C*, and that the apparent path or *locus* of the image is the ſame ellipſe ſeen obliquely by the eye at *E*, whoſe greateſt ſemiaxis is equal to the ſine nothing, the image will be at reſt while the mirror revolves round *B C*: if therefore the ſtem *B C* be ſo turned by the adjuſting ſcrews, that

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ſine of the angle *C E i*, *C E* being the coſine; and leaſt ſemiaxis the ſine of the angle *C A I*, made to ſubtend an angle whoſe coſine is alſo *C E*.

Theſe ellipſes will be formed in any part of the mirror as well as the middle of it; becauſe the ſame change of poſition of its ſurface during a revolution which is preſented to the eye in whatever place it may view the image, will be the ſame: alſo the ellipſes will enlarge with the inclination or obliquity of the mirror to the axis of motion or ſtem of it, and their eccentricity will be inverſely as the altitude of the object, if the diſtance of the eye and object from the mirror does not vary; for the angles *C E i* and *C A I*, determining the ellipſe, enlarge with the angle *B C b* or *H C b*; but the lower the object is, the nearer does the line of ſight *E S* approach the mirror, and the conjugate ſemiaxis of the ellipſe approaches to the vertex *A* of the angle *C A I*, within which it is confined; ſo that this axis, which is the ſine of the angle *C E I*, diminiſhes with the altitude of the object, while the angle *C E i*, equal to twice *B C b*, remains unvaried.

If the relative diſtances of the object and the eye from the mirror be ſuch, that the direct interval between the image *i* and the line *E C* is but little greater than *I C*, the viſible place or path of the image will degenerate into a circle: if the image is at a leſs diſtance from *E C* than this, its place will be again an ellipſe, whoſe tranſverſe and conjugate axes will have changed place with thoſe of the former one; but if the eye be at an infinite diſtance with reſpect to the object, the place of the image will be a right line at right angles to *b n*. Now from this enquiry reſult the following inſtructions:

1ſt. That ſuch an injudicious ſituation of the eye and object might be pitched upon for the adjuſtment of the inſtrument, that the image would appear to move in a circle; in which caſe it would be impoſſible to determine in what part the mirror was moſt elevated; ſo that the object choſen for adjuſtment ſhould be much more diſtant than the eye, and alſo not too much elevated above the level of the mirror; becauſe that the point *B* will coincide with *b*, (which is done by unſcrewing the ſcrew *s* 1, (fig. 2.) and ſcrewing up *s* 2,) then the plummet will bring back the ſtem *C B* from the place *b* to the line of gravity *C B*, and at the ſame time bring the diameter *b C* of the mirror to the horizontal poſition *H N*: and if the inſtrument be made with attention to the circumſtances already mentioned, the change of its centre of gravity (if any) from the plumb-line, made by alteration

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becauſe then the elliptic path of the image will be more eccentric, and it will be eaſier perceived in what part of the mirror the vertex *i* of the ellipſe is formed, which it has been ſhewn is the moſt elevated part of it.

2dly. That the perſon adjuſting the mirror muſt make it revolve a full ſemicircle, in order that both vertices of the ellipſe may be ſeen; for this, by doubling the greateſt angle of aberration, may make it perceptible, though ſingly the motion and divarication of the images could not be obſerved: for which purpoſe the inſtrument muſt be changed on the needle, and replaced with its other ſide towards the arm *K* which ſupports it: and if the caſe or veſſel, in which it is ſuſpended, could be turned partly round, it would facilitate the adjuſtment when done by the image of a very remote object.

3dly. That an obſervation may be made accurately by this level, even when it has a great error of adjuſtment; by taking the mean of the *greateſt* and *leaſt* altitudes of the obſerved object, which are diſcoverable by the greateſt and leaſt divarication of the images during a ſemi-revolution of the mirror, which will be ſeen in that diameter of it, wherein is alſo the tranſverſe diameter of the ellipſe: and in it is to be taken one of the two altitudes, and, after turning the mirror half round, the other: the mean of theſe would reduce the reflected image to the centre of the ellipſe, and is therefore the true angular diſtance or altitude. This advantage of the level did not occur to myſelf, but was ſuggeſted by Mr. Profeſſor Brinkley, whoſe regard to the intereſts of ſcience inclined him to give much attention to this inſtrument.

alteration of the ſtem, will be ſo little as to be quite imperceptible; but were that change ever ſo great, ſince the adjuſtment is made by what is afterward actually the plumb-line, it can produce no error, provided the weight which is appended remains the ſame.

By this means the level may be adjuſted to a certain degree of accuracy, but never to any thing near preciſion; this can be effected by no means that I know, ſo well as by the Hadley's quadrant itſelf, to whoſe uſe it is ſubſervient, and from which in return it moſt readily receives its perfect adjuſtment; which is done by obſerving, when the image of a very remote object, as the ſun or moon or a bright ſtar in twilight, when near the meridian and their altitude not great; or the top of a very diſtant mountain ſeen in the mirror coincident or in contact with the image of the ſame object reflected by the quadrant, at the middle or edge of the tranſparent part of the horizon-glaſs, will preſerve (in the ſame place of that glaſs) its coincidence unvaried, while the level is made to revolve half a turn round its axis: if the image in the level riſes or falls from that in the quadrant, it muſt be adjuſted by the ſcrews as before. If the quadrant is furniſhed with a teleſcope that inverts, (by the help of which the adjuſtment may be rendered far more accurate than it could be done by the naked eye) then the aſcent of the image in the mirror, from the fixed image in the quadrant, muſt be regarded as its deſcent, and *vice verſa.* Any *near* fixed object, of ſuch length in an horizontal direction as to be ſeen, when no teleſcope is uſed, in the ſilvered and unſilvered parts of the horizon glaſs, will ſerve for the adjuſtment, provided the eye be fixed, by having the quadrant immoveably placed on a ſtand, or faſtened to a board while the adjuſtment is performing; ſo that it may thus be very eaſily and accurately effected at any time even within doors, (care being taken that the floor of the room does not by ſpringing or bending change the relative altitudes of the level and object from the ground, and their angular diſtance) by fixing up as an object a ſtrip of black paper or any kind of foil, &c. on a pane of the window, extended horizontally: and a ſmall *fixed* teleſcope, furniſhed with croſs wires ſet diagonally in the tube, (that the horizontal image may appear within the angles at the centre) and the wires placed at ſuch a diſtance from the eye-glaſs, that a motion of the eye will not affect the apparent place of the image in the field of view, may be ſubſtituted inſtead of the quadrant, if it be more convenient to do ſo; the manner of performing this adjuſtment is deſcribed underneath*.

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* Unleſs the adjuſtment by a *near* object be conducted in a judicious manner, a perſon may weary himſelf in doing it, where yet there is no difficulty. Let the quadrant be ſo fixed on a ſtand or rather to an upright board, on which is faſtened the arm *K* ſupporting the level, that the two images may by the motion of the index, &c. be brought to coincide near the middle of the mirror: the mirror may then be firſt turned round on the needle, 'till ſome certain diameter of it, as ſuppoſe that in the direction

It muſt be evident from this account, that no error can happen in any obſervation made with this inſtrument, when it can be uſed at all in the abſence of high winds, if its equilibration is permitted,

direction of the pillars *a a*, be in the plane of viſion or parallel to it, and the interval and poſition of the image in the mirror, with reſpect to that in the horizon-glaſs, ſhould be remarked: the weight being then taken off, the mirror ſhould be reverſed, and its oppoſite ſide placed over the arm *K*; and when the weight is replaced, the ſame diameter of it ſhould be brought into the plane of viſion as before: the image in the mirror will now be ſeen in its higheſt or loweſt poſition in this diameter as the place it appeared in before was the contrary; and the image in the quadrant ſhould be raiſed or lowered, by moving the index, 'till this image is judged to be in the middle between thoſe two places of the image in the mirror; and this latter ſhould then be brought, by altering the two adjuſting ſcrews, which are for this purpoſe placed directly under the pillars, to coincide with the image in the horizon-glaſs. By a few trials, reverſing the mirror, and altering the place of the images, 'till that in the quadrant is got into the middle between the extreme poſitions of the other image (which is the centre of the elliptic path it deſcribes) and this latter image then made to coincide with the former, the aforeſaid diameter of the mirror will be made level; and the diameter at right angles to it will be alſo rendered ſo, by turning the mirror about on each ſide and altering the other two adjuſting ſcrews as the conſequent elevation or depreſſion of the image directs. If a teleſcope only, furniſhed with croſs wires, be uſed for adjuſtment, inſtead of a quadrant, then the directions here given with reſpect to the image in the horizon-glaſs in the quadrant, are to be applied, as if ſpoken of the centre of the croſs wires of the teleſcope. A little practice will produce ſuch a degree of dexterity in this operation, that the adjuſtment may be effected in a very ſhort time; I have done it more than once (to the exactneſs of leſs than a minute of a degree) in leſs than ten minutes. The mirror will be more eaſily turned round its axis, without producing pendulous vibrations of the weight, and adjuſted, if the weight be hung by a thread about a foot long, faſtened to the looped ſtring *t*, and made to ſwing thus in water contained not in its own caſe, but in another veſſel, 'till the adjuſtment is finiſhed: then the weight and level may be hung as before.

permitted, by having the needle on which it is ſuſpended as hard and finely pointed as the weight to be hung on it will allow, and the needle-cap properly made with a fine apex and poliſhed; for beſide the error of adjuſtment, which may while it is uſing be detected, and either remedied, or the obſervation made truly, even when that error remains, (by taking the mean of the greateſt and leaſt altitudes the level affords in a ſemi-revolution of the mirror round its axis, as has been obſerved before), it is liable to no other error but from a pendulous motion of the weight or a tremulous motion of the inſtrument itſelf from its being agitated by the wind; and if it is affected by either of theſe, it will be viſible by the vibration or tremor of the image in the level compared with that in the quadrant which remains motionleſs. And I have found that it reſiſts the action of the wind ſo well as to admit obſervations to be made in almoſt any weather in which a perſon would chuſe to take them in the open air.

But I have obſerved its ſteadineſs to depend on the following circumſtances:

1ſt. That the whole inſtrument be as light as is conſiſtent with the neceſſary ſtrength, eſpecially the parts remote from the point of its ſuſpenſion, as the edges of the mirror and the lower part of the frame and ſtem; on which account the mirror ſhould be a thin plate of glaſs, and cannot be more than three inches in diameter; but it would be much better if it did not exceed two and a half; and alſo if it were made, like a plano-convex lens, thin at the edges: indeed the mirror need not be ſo broad as the ſurface of any fluid ought to be for this purpoſe, becauſe to the very edges it is a plane, which is not the caſe with any fluid; and the contact of the limbs of the images of the ſun and moon may, when their altitude is little more than one degree, be diſtinguiſhed in a mirror of no greater diameter than two and a half inches. I have experienced that it is eaſy to find the reflected image in a mirror of leſs than two inches diameter, by advancing the eye with the quadrant as cloſe to it as poſſible; and any perſon uſed to make obſervations with a quadrant and to hold it ſteady will find this not difficult.

The action of the wind is exerted more againſt the mirror, as being a broad continued ſurface, and immediately expoſed to it, than againſt its frame underneath, which is alſo ſcreened from it by the ſides of the veſſel; the top of which, when it is wider than the mirror, ſhould perhaps be cloſed with ſuch a moveable cover, as would ſcreen every part of it except that occupied by the mirror, and prevent the wind from blowing down into it. Whatever perturbating force is exerted againſt the mirror is at the ſame time imparted to the frame, and the momentum of both produces a vibrating motion laſting ſome time, and occaſions pendulous vibrations of the weight, which are of longer duration than the tremors of the inſtrument itſelf, and are more to be prevented.

2dly. THE greater the weight is, the more will both be ſuppreſſed; ſo that the rectification of the inſtrument is within one's power; it ſhould not be much leſs than two pounds: it ſeemed to me that the greater the tremors were, the leſs were the vibrations and vice verſa; but the former were, as might be expected, diminiſhed, and the latter increaſed, by ſhortening the ſtring *t*, or by lengthening the ſtem, and contrarywiſe.* In calm weather this level will, when the arm *K* ſupporting

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* I have tried different lengths of the ſtring and quantities of the weight, without being able to make out a theory of their effects, which yet is the more important, as it is part of the theory of the pendulum; for the level with its weight is a compound pendulum, conſiſting of two maſſes of matter connected by a ſtring or wire: when I ſuſpected that the elaſticity of the ſtring might ſuffer it to extend, and ſo to permit the tremulous agitations of the mirror and ſtem without propagating motion to the weight, and exciting its whole reſiſtance, I ſubſtituted a ſtrong wire for the ſtring (each two feet long) but found that the tremors of the mirror were more laſting, and the vibrations of the weight ſooner excited by the wire than the ſtring; ſo that the latter better anſwered the deſign of the inſtrument: its length ſeemed of the leſs conſequence, ſince any length tending to ſuppreſs the tremors encreaſed the vibrations and *vice verſa*: I therefore contracted the ſtring to the length of an inch.

The tremors of the ſtem were much quicker than its oſcillations from its own gravity would be, and far more ſo than thoſe of the weight could be ſuppoſed; theſe tremors therefore were like the vibrations of a muſical chord, ſaving that this is ſtretched beyond its natural length, except when in the middle point of each vibration; whereas it is more likely that during the tremors of the mirror, the weight ſupporting it, is ſcrewed to a tree &c. be made ſteady enough by a weight, though it be not ſuſpended in water; and ſince a

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weight ſhould be kept raiſed in the water, and that the interval between the point of ſuſpenſion and the weight ſhould be thus ſhortened, than that the ſtrong wire with which I connected it to the ſtem, ſhould be ſtretched: hence ſince ſuch vibrations of muſical ſtrings are greateſt juſt after the impulſe which produces them, and die away quickly, perhaps if ſuch a compound pendulum were applied to a clock, and the ſtroke of the pallet applied near the end of its aſcent, it would be likely to acquire the cycloidal properties, by being ſhortened towards the extremities of its arch, during moſt of the inſtants of time it ſpends there; eſpecially ſince the ſame force or maintaining power, would enlarge or diminiſh the muſical and pendulous vibrations together, and might therefore adjuſt the length of the pendulum in every part of its vibration, ſo as to make its accelerating force as its diſtance from the point of reſt.

As the extent of the diſadvantages which would attend an enlargement of the ſize or weight of the inſtrument beyond what is neceſſary, may not be obvious, I muſt obſerve, that the accuracy of obſervations made by it chiefly depends on its ſteadineſs in reſiſting the wind; and ſince the action of the wind is not momentary but continued, its effect will be probably proportional to the extent of ſurface expoſed to it, and alſo to the quantity of matter it impels, and will be in a ratio compounded of both theſe, i. e. of the ſurface of the mirror and frame which is in the duplicate ratio of the diameters or dimenſions of the ſeveral parts; and of the ſolid content of the inſtrument, which is in the triplicate ratio of the ſame diameters: ſo that if the diameter of each part be made twice greater in one of theſe inſtruments than in another, the action of the wind on the former will be exerted on four times a greater ſurface than is expoſed to it by the latter, and on eight times a greater maſs: it will therefore elevate the extremity of the ſtem, and with it the appended weight, in each tremulous vibration, four times higher in the larger than in the ſmaller inſtrument: and ſince the momentum of each is proportional to the verſed ſine of the arch of its vibration (which is the height to which the weight is raiſed), and alſo to its quantity of matter; and the magnitude and duration conjointly of the tremors are as the momentum; ſo the diſadvantage ſtone or any thing almoſt will ſerve as an occaſional weight, as alſo any veſſel to hold water, in which caſe nothing is wanting to it that may not be every where ſupplied; and as the inſtrument, with the hook or arm *K* which ſupports it, might be made of a ſize not much greater than in fig. 2. ſo it may, when conſtructed in this form and ſize, be, as a concomitant to a ſmall Hadley's ſextant, an uſeful acquiſition to a traveller who would equip himſelf expeditely: with this view, and for ſecurity againſt accidents, the mirror and the whole frame might be made of poliſhed ſteel: and when it is conſtructed upon this ſmaller ſcale, the ſtem may with advantage be made a little longer than in proportion to the figure, becauſe its length has relation not ſo much to the dimenſions of the other parts, as to the length of the ſtring, and quantity of the weight appended; both which may remain unaltered.

I WOULD not have propoſed the inſtrument here deſcribed, if I imagined that the level mentioned by Mr. Vince (in his Practical Aſtronomy, page 33), or any other one, were equally eaſy in its conſtruction and uſe, and capable like this of being every where fabricated: that deſcribed by him is (as I underſtand

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of the inſtrument of double ſize will be to that of the other one in a ratio compounded of both, i. e. of 4 × 8, (or of 32) to 1, which will be reduced to the ratio of 16 to 1; becauſe when the length of the ſtem is doubled, the power of the weight to ſuppreſs the tremors is doubled: from whence appears the neceſſity of making it as ſmall and light as poſſible, becauſe the appended weight cannot be conveniently enlarged.

underſtand it), a plano-concave lens, whoſe plane ſide is uppermoſt and a reflecting level; covering a box filled with ſpirit of wine, except a bubble, which reſts under the higheſt part of the concave ſurface; being a ſort of ſpirit-level; but to procure it the accuracy of ſuch, the radius of its concavity ſhould be as great as that of the ſpirit-level; and I ſuppoſe it muſt be difficult to grind it truly to ſo great a radius *; and to find that point in the concave

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* If any kind of ſpirit-level be made uſe of to fix a reflecting plane horizontal, and its bubble were, from the attraction of coheſion between the glaſs and the included liquor, to reſt below the ſummit of the concave arch of the tube, &c. the error this will produce will be of an angle, double that meaſured by the arch of the tube between the point of reſt of the bubble and the ſummit of the tube, (as can be collected from what has and will be mentioned); now I have intimated above, that not only the ſenſibility but the accuracy of the ſpirit-level, or its exemption from errors ariſing from this cauſe, will be improved by enlarging the radius of curvature of its tube: and becauſe it has been aſſerted, that "it could not be depended upon "to greater accuracy than one minute; for that when the radius of curvature of "the level is very great, the force with which the bubble riſes to the higheſt point "is ſo very ſmall, that the leaſt adheſion of the liquor to the glaſs will ſtop it, and "its place of reſt will be uncertain,"* which ſeems to intimate, that enlarging the radius of curvature would be of little advantage: I hope I ſhall be pardoned for inſerting the following ſtatement, which inclines me to think otherwiſe; though an acquieſcence in this as a fact would be a recommendation of the level here deſcribed, which is not liable to ſuch objection, and though it is only with diffidence and reluctance I can diſſent from the very accurate and ingenious perſon who aſſerted this, and whoſe poſition I would not venture to controvert, had he ſtated his having aſcertained the fact by experiment.

Let there be two ſuch levels, whoſe curvature is repreſented by the arches *AF*, *AG*, fig. 7, *AC* being the radius of the former, and the point *A* the ſummit of both;

* Vide Ludlam's Remarks on his Aſtronomical Obſervations.

concave arch, at which a tangent plane would be parallel to the upper ſurface, and which point muſt be the centre of the bubble: alſo

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both; and let the centre of the bubble reſt, not at the point A but at D, making the angle ACD the error of the inſtrument, whoſe ſine is BD, and verſed ſine BA: the ſame line BA will be the verſed ſine of the angle of aberration in all levels of ſimilar conſtruction and regular ſhape, whatever be the degree of curvature of their tubes: for becauſe the force with which fluids move in any direction through a pipe or orifice is q. p. equal to the weight of the ſuperincumbent fluid, which in this caſe is that of a column of liquor, whoſe altitude will be AB (if while the centre of the bubble is at D, its extremity extends to A; but leſs, and equally ſo in both tubes, if the extremity reſts at a diſtance from A on either ſide); ſo the weight and height of this column muſt be in both levels the ſame, becauſe it is counterpoiſed by the attraction of coheſion (I ſpeak not of electric attraction) arreſting the liquor, and preventing the extremities of the bubble from ſettling in an horizontal plane; which attraction is the ſame and invariable in tubes of equal diameters whatever be their curvature, and therefore in both tubes AF, AG, the centre of the bubble will reſt in the line BD: let it reſt in the tube of leſſer curvature or greater radius at the point E, and in the other tube AD in D; then the arch AE, meaſuring the angle of aberration in the former tube will be to the arch AD the aberration in the latter in the inverſe ratio of the line BE to the line BD: theſe lines are the ſines of the angles; but the ſine or ordinate of a circle is a mean proportional between the verſed ſine or abſciſſe and its complement to the diameter; for if lines be drawn from the extremes of the diameter to any point in the circumference, as for inſtance, to D in the circle AD, they conſtitute an angle in a ſemicircle, which muſt be a right one, (El. 3. 31.), from whoſe vertex the ſine DB falls perpendicular on the baſe; ſo that the verſed ſine AB is to the ſine BD as this BD is to the complement of the diameter BH (El. 6. 8.); i. e. the rectangle AB, BH is equal to the ſquare of BD (El. 6. 16.); alſo in the circle AE the rectangle under the ſame abſciſſe AB, and the complement to its diameter is equal to the ſquare of BE: but theſe two rectangles, ſince one of their ſides AB is common, muſt be in the ratio of the other ſides; i. e (becauſe AB is ſo very ſmall that it may be neglected), in the ratio of the whole diameters, or of the radii which are as the diameters; which ratio is that of the ſquare of BD to the ſquare of BE; conſequently when the ſines are as 1 to 2, the diameters or radii alſo were it properly conſtructed, it would require to be adjuſted every time it is uſed or ſtirred from its place, unleſs it were ſet upon another level plane, and to make this adjuſtment would require the light of the day or of a candle; ſo that it would not anſwer to make by night and in any place obſervations of the ſtars, which are often the only ones a traveller has an opportunity of making. I apprehend it would require at every obſervation a conſiderable part of the trouble of adjuſtment, which in the level here deſcribed ſerves once for all; for after being adjuſted, it requires no farther care than to keep the needle duly pointed.

As an inſtrument which does not, like this one, detect its own errors, may gain credit for an accuracy which it has not, it will be unfair to judge of the preſent level only from a compariſon of it with ſuch a one: the faireſt trial of its adjuſtment, &c. will be made by obſervations taken in calm weather from the ſurface of a fluid of ſufficient extent, and not covered by glaſs planes. If the weight were to be faſtened to the ſtem without the intervention of a cord or hook, the tremors of the mirror would be ſuppreſſed, and the wind would communicate no motion

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radii will be as 1 to 4: if the ſines were as the radii, or as 1 to 4, the angles or arches *AD*, *AE* would be equal, but ſince *BD* is by ſuppoſition only half *BE*, and the angles are ſmall, the arch of aberration *AE* will be little more than half the arch *AD*: and hence it appears that the error of the level will be q. p. in nearly the inverſe ſubduplicate ratio of the radius of its curvature; ſo that when the radius is as 1, 4, 16, &c. the aberration will be as 4, 2, 1, &c. or as 1, $\frac{1}{2}$, $\frac{1}{4}$, &c.

motion to it, except a pendulous vibration affecting the whole maſs. The Reverend Mr. Auſtin, for whoſe judgment in theſe things I had due reſpect, adviſed me to contrive the machine on this principle; and accordingly I made it in the following faſhion, which, all circumſtances conſidered, I found to afford the moſt commodious general uſe of it, and to render it ſufficiently portable, as the whole may be contained in a round braſs caſe nine inches in length, and leſs than three in diameter, ſuppoſing that of the mirror to be two inches and a half, nor need it be much heavier than the glaſs planes commonly uſed, together with the quickſilver, &c. required with them, even when made of a ſize as large as here propoſed. It is repreſented fig. 8. in a vertical ſection through the middle and one third of the intended ſize; though I think, if it were made of only twice the dimenſions in the figure it might be ſufficient.

MN is a cylindrical veſſel or caſe, made of braſs or wood, which contains the level: in the middle of the bottom of it, (which ſhould not be liable to bend) is firmly ſcrewed a ſtrong braſs rod *EE*, tapering upward; and in the upper end of this is inſerted the needle *L*, on whoſe point the mirror reſts: the plate *A* is the mirror, *B* the braſs plate cemented to it, in which is fixed the conical cap that receives the needle: this plate *B* is immoveably ſcrewed and ſoldered to the end of the pipe *CC*, which pipe is ſeven inches and a half long, and widens downward, having a hole through its ſide juſt under the projecting part at *g*, to prevent the condenſation of air within it, when it is immerſed in water, &c. to that depth: this pipe, towards its upper end, is ſo narrow, as only to allow a ſmall vibration of it on the point of ſuſpenſion *L*, without bringing its ſides into contact with the upright ſpindle *E E*, for thus it will preſent a leſs ſurface to the impulſe of the wind; but when it vibrates on the needle, the loweſt part only of the pipe muſt be allowed to ſtrike againſt the rod *E E*, leſt the point of the needle ſhould be broken. The weight is repreſented at *P P*; it is a maſſive ring of braſs weighing about one pound and a half, ſoldered on the pipe *C C*, (or it might be caſt in the ſame maſs with it); after which the whole was carefully turned in a lathe, in order that its ſides might be equally thick all around; for thus they will lie equ-diſtant from the rod *E E*, when this is in a vertical poſition, and the inſtrument hangs freely on the point of ſuſpenſion; i. e. when the caſe *M N* is ſet on its baſe, and reſts ſteady on the ground or ſome level ſtand, or is ſo ſupported, that it remains erect, and in circumſtances fit for making an obſervation. To render it capable of being carried about in its caſe without injury, a braſs ring, having the form and indenture in it repreſented at *F F*, is faſtened within the caſe *M N*; which is done by four ſcrews paſſed though its ſides, that it, and alſo the level, may be introduced and taken out; and the upper part of the weight *P P* has a ſhoulder formed on it to fit and fill the indenture *b* in the ring, into which it is unerringly introduced by the conical part of the weight above the ſhoulder, when the weight is puſhed up to it; and this is done by advancing againſt it the ſcrews *D D*, which move through the bottom plate of the caſe

MN, and are furniſhed with locking nuts *ff* on the outſide, to prevent their looſening: when the inſtrument is thus puſhed upward in the caſe, the needle-cap at *L* is raiſed above the needle, and cannot injure its point, but may be let down upon it again by withdrawing the ſcrews *DD*. To ſteady the weight and mirror, any convenient liquor, as water, vinous ſpirit, &c. is poured into the caſe through the open orifice *O* in its ſide, to the height of the ring *FF*, and may be let out again by another orifice, (occaſionally ſtopped), near the bottom; to prevent which from running out at the ſcrews *DD*, plates of leather are interpoſed between the nuts *ff* and the bottom of the caſe: and if a ring of leather were likewiſe faſtened on the ſhoulder *g* of the weight *PP*, or in the indenture *h* of the ring *FF*, and freſh linſeed oil, eſſential oil, or any other, which would not ruſt the needle, were ſubſtituted inſtead of water (if by experience oil ſhould be found admiſſible) it would, by the preſſure of the ſhoulder of the weight *PP*, when ſcrewed up againſt the leather at *h*, be always kept in the bottom of the veſſel from running out, and nothing would be wanting to fit the inſtrument at all times for obſervation but to take off the cover *HH*, to withdraw the ſcrews *DD*, (keeping the nuts *ff* in their places, and holding the caſe upright that the oil may remain at the bottom), and then to ſet down the inſtrument. But the ſame oil could not be long uſed; for unleſs every part of the metal which it could touch were coated with tin, it would grow foul and viſcid by diſſolving the braſs, as it would alſo of itſelf in time; and in cold weather and climates it would by freezing or growing viſcid be rendered utterly unfit for this purpoſe: it has been diſapproved of by a perſon of better judgment than mine, and is only propoſed for experiment, ſhould the inſtrument be uſed in viſiting hot climates, where the needle would ruſt, and other liquors be ſcarce.

The want of adjuſtment of the level in this conſtruction is diſcovered by the motion of the image reflected from it as before-mentioned; and it is corrected by noting that diameter of the mirror, in which, during its revolution, the image appears moſt and leaſt elevated; then ſuppoſing a vertical plane in that diameter to divide the whole inſtrument, marking a line acroſs its baſe, i. e. acroſs the bottom of the weight; if a due portion of the metal of the weight near that line be filed away on the ſide oppoſite to that in which the image is ſeen higheſt or loweſt, the mirror will ſettle to the juſt horizontal poſition. For inſtance, ſuppoſe the moſt elevated place of the image ſeen in the mirror to be at the point *a* in the diameter *ab*; and that a perpendicular plane paſſing through the ſame interſects the baſe or bottom of the weight in the line *cd*; if ſome of the metal be raſped away near *d* on the ſide oppoſite to *a*, then the ſide *c* of the weight will be heavier than the ſide *d*, and will deſcend and approach nearer to the rod *EE*; and the ſide *a* of the mirror which was too much elevated, will at the ſame time ſubſide to a level poſition: and when this is once effected exactly, ſeeing that the inſtrument is one ſolid inflexible maſs, whoſe centre of gravity cannot alter, it is plain that unleſs it ſhould receive ſome injury, it will never after require any adjuſtment; but if it ſhould, it may eaſily be rectified in the ſame manner.

To make the level more ſteady in the time of obſervation, a tripod ſtand like that of a teleſcope might be fixed to the bottom of the caſe *MN* to ſupport it; the feet of which might be contrived to turn upward and reſt againſt the ſides of the caſe, when the inſtrument is not uſed. I could deſcribe a mode of doing this, but can add no more to this paper, the length of which demands from me an earneſt apology; obſerving only that as this level, if made on either of the two conſtructions here mentioned, may be adjuſted to the utmoſt accuracy, ſo it alſo reſiſts the agitation of the wind as well as the fluid level covered with glaſs planes, unleſs the quickſilver in the latter be likewiſe ſheltered by a glaſs plate laid on its ſurface, which if the quickſilver ſhould happen to be ſpilled would be uſeleſs; and ſuppoſing the plate to be of ſuch uniform thickneſs and denſity, and to float ſo equidiſtant from the depreſſed margin of the quickſilver on every ſide, no air bubbles likewiſe intervening nor accidental contact with the ſides of the veſſel, that it would naturally lie parallel to the ſurface of the fluid, yet if this ſhould accidentally be ſo overſpread with duſt or foulneſs, as to raiſe one edge of the plate, and depreſs the other, even ſo little as the thirty-three-thouſandth part of an inch, it might give an altitude one minute of a degree erroneous:* and as theſe accidents are likely to happen to a perſon uſing that kind of level in travelling, ſo I am perſuaded the inſtrument here deſcribed would remain longer ſerviceable to a traveller, than any other for this purpoſe that I am acquainted with: and it is as being the moſt ſafely portable of any, and alſo manageable abroad at night when others are not ſo, that it is chiefly recommended; though after many comparative trials of the fluid level with this one, I would, without conſciouſneſs of partiality, generally prefer the latter; for it is in fact a plummet, and may be made and adjuſted to have the accuracy which in aſtronomical uſe, and like circumſtances, the plummet affords.

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* If the radius of a circle be ten inches, each inch divided into a thouſand equal parts, i. e. in the whole ten thouſand, the ſine of the arch of one minute is (not quite) three of thoſe parts, or the $\frac{1}{3333}$ part of an inch: if the radius be only the $\frac{1}{5}$ of this, or two inches, the ſine of one minute will be only the $\frac{1}{5}$ of $\frac{1}{3333}$ of an inch; i. e. the $\frac{1}{16665}$ part: conſequently if the reflecting plate or mirror abovementioned were four inches in diameter, and it were accidentally tilted up at one edge, and depreſſed on the oppoſite one, even ſo little as the $\frac{1}{16665}$ part of an inch, it would be one minute of a degree oblique to the horizon: but I have ſhewn, that the greateſt error of obſervation by a reflecting level, is always double the error of the ſpeculum; hence half the above angle of obliquity of the ſpeculum to the horizon, or an elevation and depreſſion of its oppoſite edges from it, of the $\frac{1}{33330}$ part of an inch, (and how ſmall a quantity this is, I leave to the conception of the reader) will, if the diameter of greateſt obliquity happen to be in the plane of viſion, produce an error in the obſervation amounting to one minute: the ſame is true of the level here deſcribed; ſo that the property of a ſcrew in producing ſmall motions is admirable, ſince its adjuſting ſcrews, even at the ſame diſtance (two inches) from the centre of motion, can in rectifying the ſpeculum, be made to advance with preciſion enough, through a ſpace far leſs than this, even ſo ſmall as the one-hundred-thouſandth part of an inch.

It is eaſy to conceive that the greater the ſize of this level is made *in length*, when it is conſtructed in the form in fig. 8, the more accurate will it be, and ſteady in reſiſting the agitation of the wind. Alſo that this faſhion of it admits the more eaſy adjuſtment, as the mirror can be turned quite round on its axis, and the higheſt and loweſt place of the image inſtantly diſcovered, conſequently its error, if it has any.